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Ocean Through The Sensor (TTS) Update

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Abstract

Traditional geoacoustic and ocean data collection efforts by skilled scientists will always be a cornerstone of the Naval Meteorology and Oceanography (MetOc) Program. In recent years however, other methods have been explored to further expand the scope of these data collection efforts. This effort has been driven, in part, by a declining MetOc Program Budget combined with other programmatic considerations both within and outside the Naval MetOc Program. PEO C4I and Space PMW 150, in conjunction with CNMOC, NAVOCEANO, NAVSEA, NAVAIR, and scientists from ONR, NRL, and various National Laboratories and industry, are focused on developing new methods to sense the environment, either through direct or inferred measurements, using tactical sensors. One of these efforts is focused on the development of Through-The-Sensor (TTS) technology. This effort seeks to use data from tactical sensors to characterize the battlespace environment. These data can then be used in Fleet Tactical Decision Aids (TDAs) to modify ASW and MIW tactics and enhance situational awareness at the single ship, Carrier Strike Group (CSG), Expeditionary Strike Group (ESG) and Theater USW (TUSW) level. Near term efforts include the exploitation of various mine-hunting sensors such as the AQS-20 and side scan sonar and submarine sensors such as the Precision Undersea Mapper (PUMA) and tactical towed arrays. Exploitation of sensors further on the horizon include submarine sensors such as the submarine CTD and fathometer (BQN-17), the surface ship Instrumented Tow Cable (ITC), and the air community's Tactical Acoustic Measurement (TAM) Buoy.

Background

The need to exploit tactical sensors for MetOc data collection to provide direct feedback into Tactical Decision Aids as well as the sensors themselves was noted in the late 1990's. CNO N096 and SPAWAR commissioned a study in 1998 to ascertain where funding directed towards USW support would best be spent. One of the findings of this study[1] directly pointed towards increased efforts in the area of Through-The-Sensor (TTS) data collection since it was noted that the largest errors in acoustic Transmission Loss (TL) resulted from poor data vice inaccurate models. Another driver in the philosophical switch from developing MetOc specific sensors to developing techniques to exploit tactical sensors already on-scene, was the fact that prototype sensors are extremely expensive to develop and the fact that Fleet interest in buying, training,

[1] "Shallow Water Issues for Meteorology and Oceanography (SWIM) Report," SPAWAR PMW 155, 22 February 1999.

and maintaining MetOc specific sensors was less than enthusiastic. To this end, the CNO N096 MetOc Program Operational Concept[2], valid for the timeframe from 2007 to 2015, specifically discourages further development of these types (i.e. MetOc specific) of sensors, noting:

> *"We will not develop or use stand-alone METOC sensor equipment, except when no alternative means exists to support the Operational Concept.[2]"*

The Operational Concept further reiterates the need for the development of TTS technology in it's guiding principles, stating, in part:

> *"We will conduct near real time measurements, analysis, and "nowcast" of relevant METOC parameters throughout the battlespace, including denied areas. We will exploit all-source remote sensors and through-the-sensor methods to take advantage of existing warfare sensors and platforms.[2]*

One of the key assumptions required to execute this particular guiding principal is that:

> *"Through-The-Sensor Technology (TTS) will be available (to some extent) to support characterization of the battlespace environment.[2]"*

Most recently CNMOC, as part of its Zero Based Review (ZBR), noted that:

> *"Major POM 06 investment themes derived from ZBR include developing stand-off survey capability via use of unmanned vehicles, expansion of through-the-sensor data collection/processing efforts, and focusing community assets to provide tactical support to warfighters.[3]"*

Because of these developments PMW 150, in close coordination with CNMOC, NAVOCEANO, NRL, ONR, and other Systems Commands, are focusing on maturing technologies critical to the TTS concept. These technologies focus on both atmospheric, oceanographic and geoacoustic data acquisition. This article will focus on efforts directed towards TTS collection of oceanographic, acoustic, and geoacoustic data only. A follow-on article will address atmospheric TTS efforts, specifically the Tactical Environmental Processor (TEP) project, UAVs, the SPS-48E effort, and others. The basic reason we need to characterize the battlespace is the topic of another discussion, but should be apparent to most of the audience this paper will reach. One favorite example though, is the simple need for high-resolution bathymetry in support of precision ASW operations. The top picture in Fig 1 shows how the acoustic field is perturbed in the presence of a seamount. The use of a low-resolution database (bottom picture) that might not have shown this seamount would result in the sonar operator believing he is operating in a bottom bounce environment when, in fact, he is actually operating in a completely different environment.

[2] "Naval Oceanography Program Operational Concept," CNO N096, March 2002.

[3] "MetOc Zero-Based Review Summary And Update," COMNAVMETOCCOM 212118Z OCT 03.

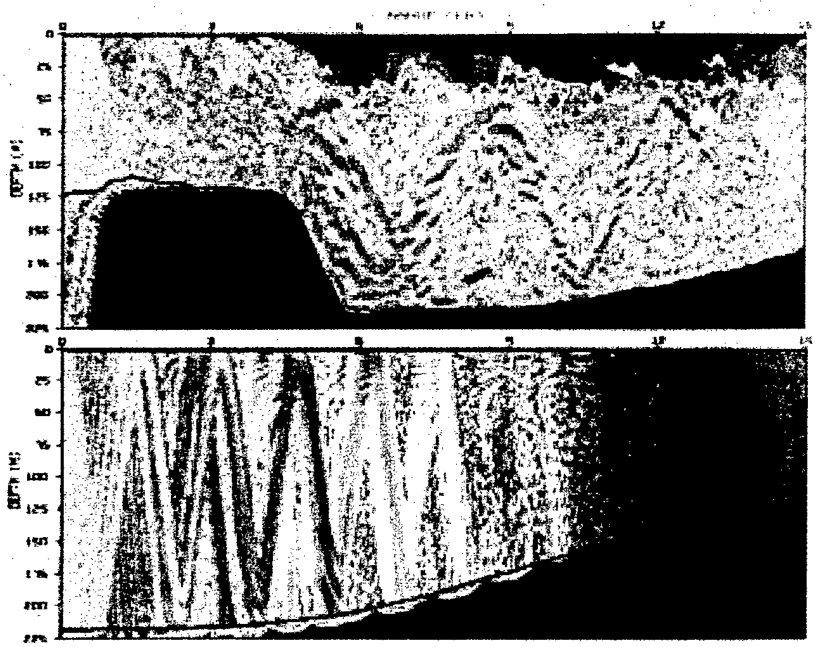

Figure 1. Acoustic propagation field in the present of a seamount (top) using high-resolution bathymetry and without a seamount (bottom) sing lower resolution bathymetry (DBDB5).

TTS Goals and Objectives

While no formal definition of TTS exists, the following is offered: "Use of any organic Naval sensor to either directly measure or infer specific MetOc parameters. These can be volumetric measurements from tactical sensors (e.g. radars, active and passive sonars, etc.), point or time-series measurements from reconnaissance sensors (e.g. UAVs, UUVs, SUVs, etc.), or time-series measurements from sensors designed to assess MetOc parameters but developed outside of the MetOc Program and already integrated into aircraft, submarines, and surface ships (e.g. submarine Conductivity, Temperature, and Depth (CTD) sensors, surface ship Instrumented Tow Cables, aircraft temperature and wind speed sensors, the NAVAIR Tactical Acoustic Measurement (TAM) Buoy, the submarine Precision Undersea Mapper (PUMA) system, surface ship and submarine fathometers, Satellite sensors, etc.). " The reader is invited to participate in refinements to this definition. The motivation is to glean data from sensors that are already out there and, from a fiscal standpoint, that someone else paid for.

The technical goals of developing TTS techniques are to provide near-real-time feedback to the sensor, TDAs, and models to allow the:

- Platform and CSG/ESG to optimize both sensor performance and modify tactics and plans in real-time;
- Theater USW Commander to properly plan for required assets and pre-positioning in near-real-time; and,
- Update of the NAVOCEANO Navy Standard Databases in the long term.

Further, implementation of TTS techniques must be minimally intrusive to the combat system and not interfere with the primary mission, safety, or vulnerability of the platform.

As an aside, the goal of organic TTS data collection and assimilation is not to replace the on-going high quality scientific survey efforts conducted by NAVOCEANO for many years, rather the goal is to augment these databases with measurements made in denied areas or in other areas

where either lack of data, or inadequate data resolution, precludes precision planning and execution of USW operations in support of Sea Power 21 tenants.

Enabling Technologies

In general, the following elements are required to implement a TTS technique into a given system and platform:

- Access to the data flow (e.g. a signal processor) of a particular sensor;
- A data storage mechanism;
- A TDA with a high speed acoustic Transmission Loss (TL) engine that can process the sensor data then interpret and tactically exploit data gleaned from the particular sensor;
- An onboard network connecting all of the above as well as a Naval Network connecting ships and aircraft; and,
- An off-hull data transport mechanism.

A notional diagram of how such a setup would look, in the case of the MK 2 submarine Combat Control System, is shown in Fig 2.

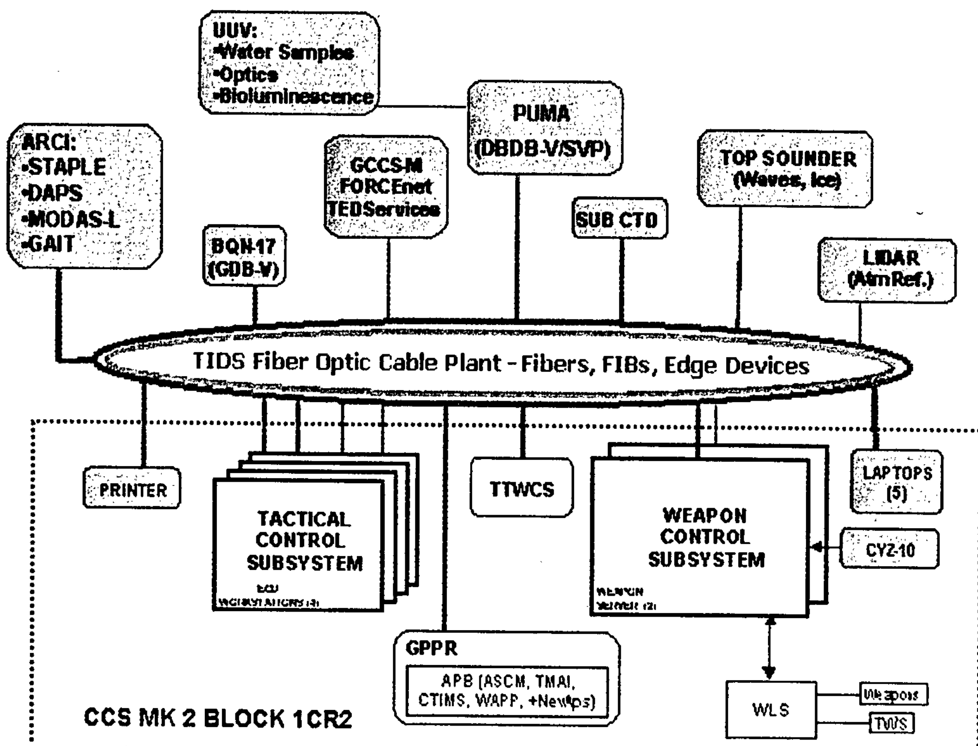

Figure 2. Notional integrated submarine combat system architecture that shows connectivity between the various sensors, TDAs, and C4I.

These elements can be realized through the following:

- The advent of inexpensive high capacity data storage;
- The PMW 150 developed low cost, high-speed, small footprint processors TL engine called the Scaleable Tactical Acoustic Transmission Loss Engine (STAPLE);
- The availability of shipboard intranets such as IT-21 and the Tactical Integrated Digital System (TIDS) on submarines. TIDS (see Figure 2) is a fiber optic data bus that ties major electronic systems on a submarine together "allowing for data transfer between sonar, the fire control system, electronic support measures (ESM) and radio[4]." Backfit of this system will be competed by FY04.
- Increased bandwidth allowing for the implementation of FORCEnet within the Navy as part of the DoD wide Global Information Grid Enterprise System (GIG ES) [5], which will allow for offboard data transport.
- The incorporation of the PMW 150 Tactical Environmental Data Services (TEDServices) effort that will provide a mechanism for MetOc data transport within the FORCEnet/GIG ES architecture. PMW 150 has recently released a letter detailing the build plan and distribution of this system[6].

In summary, the TTS model, and many of the associated algorithms (i.e. "the science"), is not really a new or revolutionary concept. The revolutionary technical developments that are making this effort feasible are associated with the advances in communications, computing power, and computer networking.

Ongoing Efforts

Several TTS efforts are currently underway and in various stages of development. A summary of these efforts, as well as future efforts, is presented in Table 1. The following paragraphs provide a short overview of these efforts.

a. The Geoacoustic Inversion Toolkit (GAIT). The GAIT effort seeks to provide for a set of validated Navy approved algorithms (i.e. as part of OAML) that can be applied to a wide range of acoustic sensors and situations (i.e. tactical or non-tactical timeframes) to gain information on the geoacoustic characteristics of the ocean bottom. These data will then be used to populate local databases for use by acoustic TL engines resident within TDAs. These data will also be archived for use by NAVOCEANO in updating their Navy Standard Databases. Fig 3 shows the various algorithms that reside within GAIT. This effort began in 2000 with the development and identification of potential algorithms. This initial effort was followed by an international workshop in May 2001 that was designed to evaluate the various algorithms and down select best of breed for inclusion in GAIT Version 1.0. This effort is thoroughly documented in a recently released special edition of IEEE Journal of Ocean Engineering[7]. The second and final installment will be issued in another special edition of IEEE JOE to be published in January

[4] "U.S. Navy Submarine Central." http://www.chinfo.navy.mil/navpalib/ships/submarines/centennial/subinno.html.
[5] "DOD Net-Centric Data Strategy," DoD CIO Memorandum of 09 May 2003.
[6] "TEDServices Functional Description and Distribution," PMW 150 ltr 5239 Ser PMS 150/104 of 09 September 2003.
[7] "IEEE JOE Special Edition on Geoacoustic Inversions, October 2003.

2004. IV&V is currently underway and expected to be completed in spring 2004 followed by OAML certification in the summer of 2004. Associated with this effort is the development of the Geoacoustic Database – Variable resolution (GDB-V) database. This database will be used to store measured data onboard using an object-oriented architecture. Expected GAIT transition paths are shown in Table 1.

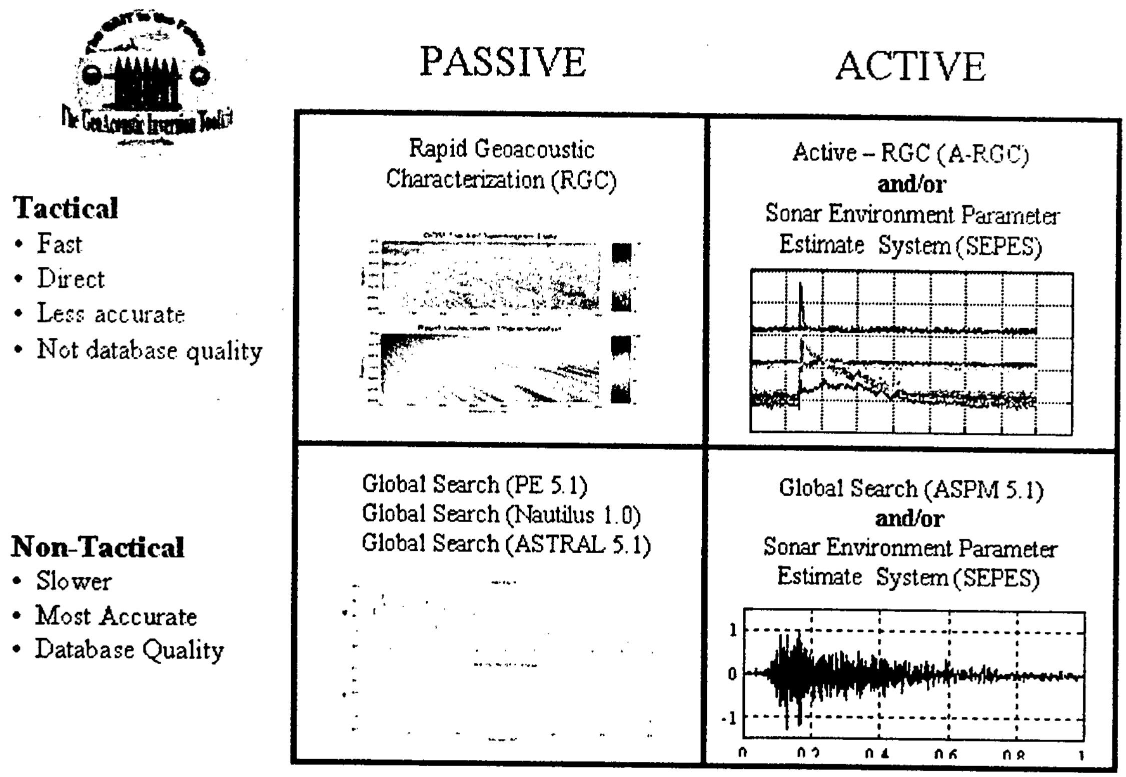

Figure 3. Breakdown of the Geoacoustic Inversion Toolbox (GAIT) algorithms into Passive (tactical and non-tactical) and Active (tactical and non-tactical) applications.

Table 1. List of ongoing and potential TTS efforts broken down by data types (atmospheric, oceanographic, bathymetric, and geoacoustic), sensors, transition path, and effort.

TTS - Atmospheric			
Tactical Sensor	**Transition Path**	**TTS Effort**	**Data**
SPY-1	Aegis Display	TEP/RFC	Refractivity, Reflectivity, Velocity, Turbulence, Clouds, Wind Fields
SPS-48E	CVTV, OA Div, etc.	SPS-48E Weax Radar	Weax Radar, Feature Tracking
UAV	UAV Ground Stations	Tactical Battlefield Sensors	T, P, RH, Chem/Bio, Target WX
Military ACARS			T, P, RH, Winds
TTS - Oceanographic			
Tactical Sensor	**Transition Path**	**TTS Effort**	**Data**
SubCTD	STDA	SubCTD	T, S, D
PUMA	STDA	SVP Inversions	SVP
LMRS/LPUMA	STDA	SVP Inversions	SVP
AQS-14/20	MEDAL	Adaptive Sensors/Surveys	SVP
SQR-19/TB-23/TB-29	STDA/SPPFS STDA	DAPS	Ambient Noise
ADS	STDA(I)	DAPS	Ambient Noise
ITC (MFTA)	SPPFS STDA	ITC-TEDS Integration	T, D
UQN-4	STDA/NITES	Nephaloid Inversions	Nephaloid layer
UUV	UUV Display	Tactical Battlefield Sensors	Bioluminescence, Transmissivity, Currents, T, S, D
Tactical Acoustic Measurement (TAM)	TAM Decision Aid (TAMDA)	TAMDA	Ambient Noise, Acoustic Transmission Loss
TTS - Bathymetric			
Tactical Sensor	**Transition Path**	**TTS Effort**	**Data**
PUMA	STDA/MEDAL	PUMA-TEDS Integration	Bathymetry, MLCs
BQN-17	STDA	BQN-17/TEDS Integration	Bathymetry
LMRS/LPUMA	STDA/MEDAL	PUMA-TEDS Integration	Bathymetry, MLCs
AQS-14/20	MEDAL	Adaptive Sensors/Surveys	Bathymetry, MLCs, Change Detection, Side-scan
UQN-4	STDA/MEDAL	UQN-4/TEDS Integration	Bathymetry
TTS - Geoacoustic			
Tactical Sensor	**Transition Path**	**TTS Effort**	**Data**
PUMA	STDA	GAIT V1.0	GDB-V
BQN-17	MEDAL	ASCS - BQN-17/ TEDS Integration	Sediment Classification/GDB-V
UQN-4	STDA/MEDA	ASCS – UQN-4	Sediment Classification/GDB-V
LMRS/LPUMA	MEDAL	GAIT V1.0	Sediment Classification/GDB-V
AQS-14/20	MEDAL	Adaptive Sensors/Surveys	BBS/GDB-V
LBVDS, LFA, EA-53C, SH-60R (ALFS)	SPPFS STDA/STDA(I)	GAIT V1.0/EAST	GDB-V
HEP/TAMDA	SIIP/TSC	GAIT V1.0/HEP Automation	BBS/GDB-V
SQR-19/TB-23/TB-29	STDA/SPPFS STDA	GAIT V1.0	GDB-V
ADS	STDA(I)	GAIT V1.0	GDB-V
UUV	UUV Display		Sediment Classification/GDB-V
Tactical Acoustic Measurement (TAM)	TAM Decision Aid (TAMDA)	GAIT V1.0	GDB-V

b. Sidescan Sonar. This effort, led by the Mine Warfare Fleet Liaison Team at NAVOCEANO (N81), seeks to database sidescan imagery collected by Navy Mine Warfare assets. As the number of Fleet sidescan sonars increases, the size of this database will significantly increase over the next several years. This database will be used to develop change detection and other capabilities in support of Mine Warfare operations.

c. The Acoustic Sediment Classification System (ASCS). Scientists at NRL SSC developed the ASCS. It uses impedance matching techniques to infer bottom type through submarine fathometers (BQN-17) and surface ship fathometers (UQN-4). The ASCS capability has been demonstrated on two SSN 's and two MCM's with more to follow. The ASCS is currently operational on PORTSMOUTH as part of a TEMPALT. The UQN-4 TTS effort is quite mature with respect to sediment classification. It has been demonstrated extensively on MCM ships and used operationally during Operation Iraqi Freedom. OPNAV N752 has committed to the inclusion of this technology in POM06 submissions as an upgrade to the Battle Space Profiler program of record. It is expected that this system will also feed the GDB-V database.

d. Precision Undersea Mapper (PUMA). This effort began in 2001 under the auspices of a sponsor level MOA between N096 and N77 as well as a SYSCOM MOA[8] and revolved around the collection, decimation, and formatting of high-resolution bathymetric data obtained through the submarine PUMA system, a high-frequency forward looking sonar. ARL UT, NRL SSC, and NAVOCEANO completed development of the required algorithms in 2003. Current efforts to integrate these algorithms into STAPLE and the submarine STDA are currently underway and expected to be complete in 2004. These data will be used onboard in STDA and eventually sent to NAVOCEANO for updating the DBDB-V database in the near-term. Further down the line, when TEDServices has the capability to ingest and transmit these bathymetric data, it will be an integral part of this effort. This capability is targeted for incorporation into TEDServices Build 0, Version 2.0, scheduled for release Q4FY05[6].

e. AQS-20 Minehunting System (to be towed by the Remote Minehunting System or an MH-60). This effort, led by NRL SSC, is focused on the development of an end-to-end TTS environmental data collection concept of operations using the AQS-20 mine hunting sensor. NRL SSC is developing an end-to-end concept that includes the entire process, from sensor data collection through processing, fusion, distribution and use in TDAs. "Dynamic, near real-time, and historical data will be processed and merged onboard and provided to the MEDAL TDA as the "best" environmental picture to support Mine Countermeasures. Data types include swath bathymetry and sediment information[9]." The target databases for this TTS effort are GDB-V and DBDBV. While this newer effort is focusing on end-to-end data collection from sensor to decision aid, TTS data collection from the AQS-20 (from an MH-53 helicopter) has already been

[8] "ASTO/PMS 425/PMW 155 Precision Underwater Mapping (PUMA)/Tactical Environmental Data Server (TEDS) Integration Memorandum of Agreement," 12 April 2001.
[9] "AQS-20 TTS Environmental Data Collection, Fusion and Dissemination from an HSV," Rapid Transition Proposal, 30 June 2003.

demonstrated[10]. The end-to-end AQS-20 R&D effort is scheduled for completion in FY06 and includes a demonstration on an HSV.

f. Tail AN data collection and databasing. Ships and submarines regularly collect tail ambient noise data however it is not currently stored. NAVOCEANO is leading an effort to begin collecting these datasets for use in a web-based system that will:

- Permit the cross platform use of TTS ambient noise data;
- Provide beam noise rosettes, based on real time and/or historical data, for area characterization and use by ASW mission planners;
- Allow NAVOCEANO to use these data to update Navy Standard Databases;
- Provide a method for merging measured directional ambient noise with the OAML Navy standard Shipping Noise database.

Many of these efforts are already incorporated into MOAs with the Common Undersea Picture (CUP)[11] and Sonar Tactical Decision Aid (STDA)[12] efforts.

Future Efforts

In addition to the ongoing efforts, there are a plethora of potential efforts coming down the line. For example, submarines are being backfitted with a CTD capability. Additionally, the MODAS-Lite developers (NRL SSC) are working on algorithms to continuously ingest these time series measurements along the submarine's path. This "string" data ingestion capability will allow for real-time updates of the ocean environment in the vicinity of the submarine's path. The MODAS-Lite string data ingest effort is scheduled for completion in 2005. The new Multi-function Tail (MFTA) will also have an Instrumented Tow Cable (ITC) that will provide continuous temperature and depth measures. Ingest to MODAS-L could be accomplished in a similar manner. The Littoral Mine Reconnaissance System (LMRS) is another candidate for bathymetric data collection in the same vein as PUMA and installation of ocean sensors on UUVs is being explored. Finally, as a follow-on to GAIT, efforts to infer (invert) for water column parameters (i.e. sound velocity, temp, depth, etc.) through active and passive sonars will be a new focus area over the next couple of years. A rough timeline of current and future efforts is shown in Fig 4. At some point, it is envisioned that virtually all variables going into TL calculations would be from measured or inferred data.

Of course, the ultimate goal is a fully networked sensor grid feeding a Common Environmental Picture. This will be accomplished by tying all of these TTS efforts into the Combat and C4I systems in an integrated fashion (see Fig 2). This will allow for data feeds into the Virtual Natural Environment (VNE). However, this will require a coordinated CONOPS between the various shore based MetOc Production Centers, Domain Authorities, Centers of Expertise and the remote data collection points. A key to this architecture will be TEDServices and the

[10] "Environmental Data Collection from the AQS-20," Michael M. Harris, William E. Avera, Leonard D. Bibee and J. Mark Null, Journal of the Society for Counter-Ordnance Technology, 27 May 2002.
[11] "Memorandum of Understanding Between PMS 411 and PMW 155 for the Common Undersea Picture (CUP)," PMW 155 ltr 3140 Ser PMW 155/183 of 04 Dec 2002.
[12] PMW 150, PMS 425, PEO(IWS5B), and ASTO MOU of 18 April 2003 (Draft).

FORCENet infrastructure. TEDServices expects to be fully compatible with many of the TTS efforts noted above in Build 0, Version 2.0, scheduled for release in Q4FY05[9]. Notional CONOPS have already been worked in the case of PUMA[13] and inversion CONOPS are in the early stages of development[14].

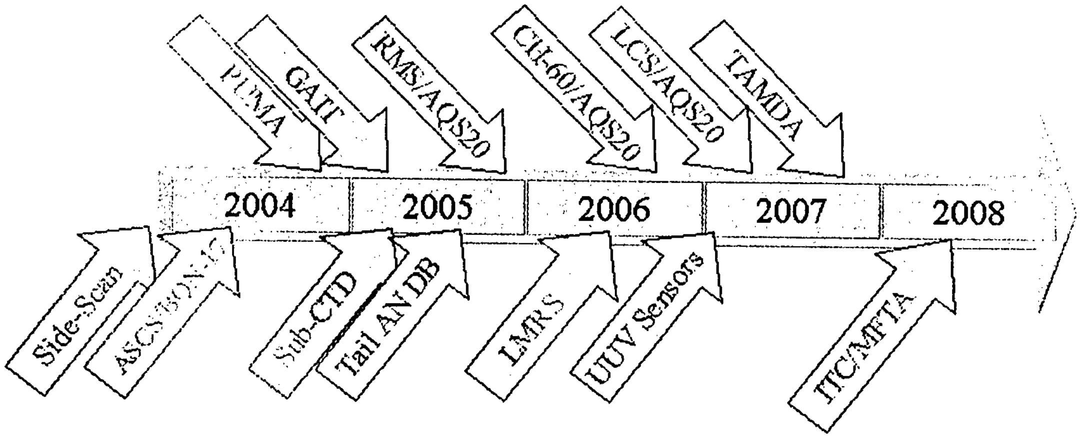

Figure 4. Rough timeline denoting IOC for various sensors and inversion techniques.

Technical Issues

There are numerous technical issues associated with these efforts. One of the main issues that go across virtually all efforts is the problem of merging high-resolution data collected on-scene with Standard Navy Databases. This process is required when a TL radial runs from measured data into historical data. This issue has been addressed with respect to bathymetry by DBDB-V 5.0 but not for geoacoustics, which will be an order of magnitude more difficult to resolve.

Another technical issue revolves around the need for a "universal data base" solution that would standardize TTS data storage. Such a database should be flexible enough to support current and future TTS data types and yet efficient enough to support the historical Navy Standard Databases. It is also critical that the database system be closely tied to the TTS platforms to ensure "off-line" archival, but also capable of feeding directly into environmental data propagation systems like TEDServices whenever they are "on-line" within the host environment. Early investments into such a database will provide a jumpstart for follow on TTS systems, enable TTS systems and TDAs to share dynamic datasets (e.g., GAIT utilization of PUMA and/or AQS-20 bathymetry), enable rapid incorporation of TTS datasets into historical products, and facilitate near real-time "merge" algorithms that fuse dynamic and historic data. To this end scientists at NRL and NAVOCEANO are developing GDB-V. Besides being the conduit for "dynamic" data collected on-scene, it is envisioned that GDB-V will become the basis for a broad Navy Standard Database that will consolidate and eventually replace the current Navy

[13] "Concept of Operations for Data Use and Distribution of PUMA Data (Revision 5)," Kim Koehler, PMW 155, 06 September 2001.
[14] "Concept of Operations for Geoacoustic Inversion Techniques (DRAFT)," Marc Stewart, APL UW, 25 August 2003.

Standard Databases such as DBDB-V, HFBL, LFBL, SST (Surface Sediment Type) and the sediment roughness database.

Conclusion

TTS technology must continue to be developed if the MetOc community is to realize meaningful implementation of the VNE concept in support of the Common Undersea Picture and other efforts critical to the success of Sea Shield, Sea Strike, and Sea Basing. It is a major MetOc "transformational capability" that will enable the MetOc community to be a major player in Sea Power 21. The TTS technology envisioned by the N096 Operational Concept will be realized in the timeframe of interest.

OPNAV, PMW 150, the Science and Technology community, in conjunction with the various Platform Sponsors and other Systems Commands, are engaged in evaluating the maturity of the various TTS technologies and are forging ahead with integration into various combat systems and TDAs. We are rapidly realizing that integration of TTS technologies is an order of magnitude harder than traditional MetOc support since it requires broad coordination across numerous organizations. Development of the scientific algorithms is relatively inexpensive however the cost of integrating these algorithms into sensor and combat systems is not. The challenge is to show the direct and immediate benefit to warfighting effectiveness by upgrading combat systems with these technologies.

More details on PMW 150's TTS efforts, as well as other PMW 150 acoustic related R&D efforts, can be found in the Acoustic R&D Execution Plan[15], available upon request. Additionally, more technical information on the GDBV database[16,17,18] described earlier, as well as the overall TEDServices concept[19], can be provided upon request.

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[15] "Acoustic Research and Development FY03-FY04 Execution Plan and FY05-FY09 Outlook (Revision 3)," PEO C4I and Space, PMW 150, 28 February 2003.

[16] "Geophysical Data Base – Variable Resolution (GDBV): Database Definition Document," Chad Steed, NRL Stennis Space Center Technical Paper, NRL/FR/7440--03-10,063, October 2003.

[17] "VGRID: A Generic, Dynamic HDF5 Storage Model for Geo-referenced, Grid Data," Chad A. Steed, James E. Braud, and Kim A. Koehler, MTS/IEEE OCEANS 2002 Conference Proceedings, October 2002.

[18] "Geophysical Data Base Variable Resolution (GDBV): An Object-Oriented Database for Dynamic Geo-Acoustic Data Storage," Chad Steed, David Harvey, Kim Koehler, and Bruce Northridge, MTS/IEEE OCEANS 2003 Conference Proceedings, September 2003.

[19] "Gaining Tactical Advantage through Undersea Oceanographic Data Collection and Distribution from Navy Platforms by Exploiting Through The Sensor (TTS) Technology and Net-Centric Warfare (NCW) to populate the Virtual Natural Environment (VNE) as Part of the Navy Four Dimensional Cube (4DCube)." Kim Koehler and CDR John Kusters, MTS/IEEE OCEANS 2002 Conference Proceedings, October 2002.